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Water erosion and the use of solar radiation for forage species in the Coxcacoaco river basin, Mexico

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Abstract

In order to evaluate the advantages of using EPIC program (Erosion Productivity Impact Calculator) on simulation of solar radiation use, water erosion and dry matter yield of three forage species, a trial was carried out in Coxcacoaco river basin of Mexico state. Two grasses (*Chloris gayana* and *Hilaria cenchroides*) and one legume, alfalfa (*Medicago sativa*) were evaluated for dry matter yield in soils classified as Lithic Usthorthents. Dry matter yield was calculated in plots for 5 months and water erosion estimated by Universal Soil Loss Equation. Later simulation of solar radiation use, water erosion and dry matter yield of the same species were evaluated using EPIC program. Results showed that under conditions of this area, Rhodes grass (*Chloris gayana*) was most efficient in solar radiation use with values of 28.25 and 33.68% higher to found in native grass (*Hilaria cenchroides*) and alfalfa (*Medicago sativa*), respectively. On the other hand, results showed that EPIC program tends to underestimate solar radiation use and to overestimate water erosion with this species. However, under total soil covering conditions, the program is an excellent dry matter yield simulator with this species.

Key words: EPIC, simulation, soil losses, solar radiation, grasses

Introduction

Simulation has been a tool used on the useful obtained information of agriculture knowledge in order to make decisions, therefore farmer can prove with few risks, other handling alternatives (2). The necessity of evaluating the changes of use and handle of soil as well as the

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productivity of crops, have caused the recurrence with more frequency of the use of simulation models by being cheaper than doing real measures, besides of not modifying the environment (14). Among these models, EPIC (Erosion Productivity Impact Calculator) is very used to simulate lost of soil and productivity of the crop (9). This model can be used by planners in order to establish the control's goals of the erosion in function of the conservation techniques and actual productivity of crops. Besides the climatic component of EPIC, it is able to generate precipitation, temperature and solar radiation for long series of time (14). In Mexico, cattle raising is the work and sustenance of many rural communities and on the geographical region where was done the research, the most important alimentation source are pastures with grass and legumes; here soil's lost by water erosion is one of the main causes of the impoverishment of the soil that reduces the handling alternatives of the basin (3). The potential yield of the plants is in function of the interception estimate and the efficiency in the use of solar radiation to convert carbon dioxide into dry matter (17), therefore, this is the aim of the research, to realize the importance of knowing through simulation, the behavior toward solar radiation of the most used forage species for the support of flocks in a location on the East of the basin, estimating the potential lost of the soil by water erosion.

Materials and methods

This research was done on the East area of the Coxcacoaco's river basin, located on the snow-capped sierra, on the coordinates 19º 29'53" North and 98º 47' 55" West, on San Miguel Tlaixpan parish, Mexico. The area is at 2550 msnm with mean annual temperature from 12 to 18ºC, with an average slope of the land of 10%.

In 6 smallholdings of 16 m^2 each, the production of dry matter of two grasses (*Chloris gayana* e *Hilaria cenchroides*) and one legume (*Medicago sativa*) was monthly evaluated during all the rainy period (July-October). For this, four samples of 0.1 m^2 by smallholding were taken, with cuts at 5 cm of height, using a square frame of 50 cm x 20 cm. After drying them on a stove at 60ºC, were weighted with the purpose of obtaining the quantity of dry matter by area.

A perforation of 105 cm deep was done on the experimental unit, in order to study the profile and classify the soil with the USDA key (12). The profile description was done according to the methodology of Cuanalo (4) with their corresponding laboratory analysis (15).

With the climatic information of the area and using the EPIC software, the calculus of the sun radiation and the index of the foliar area for each forage specie was done. The intercepted photo-synthetically active radiation (PAR) was obtained with the Beer law (5), using the extinction coefficient of the light of each crop.

$IPAR = 0.5 \times SR\ (1-e^{(-k \times LAI)})$

Where: IPAR= intercepted photosynthetic active radiation (MJ m^{-2})

SR= Global solar radiation (MJ m^2 day^{-1})

K= Extinction coefficient of the crop's light (dimensionless)

LAI= Index the foliar area (m^2 m^{-2})

With the information of dry matter and with those of IPAR the efficient use of the radiation (RUE) for each specie was measured, which is represented by the slope of the straight line that is the result of the relation between the production of dry matter and the interception of the photosynthetically active radiation (PAR).

Using the Universal Soil Loss Equation (A = R K L S C P) water erosion was measured on each smallholding

Where:

A: Annual soil loss (t ha^{-1})

R: Rain erosion (MJ mm ha^{-1} h^{-1})

K: Erosionability of the soil (t ha h MJ^{-1} mm^{-1} ha^{-1})

L: Slope's longitude (dimensionless)

S: Slope's degree (dimensionless)

C: Handle of the crop (dimensionless)

P: Mechanical practices (dimensionless)

On the equation, the value of R was measured with the modified Richarson methodology (8). Other parameters were calculated according to the soil loss hand out by water erosion (6). Likewise, it was proceeded to simulate the water erosion with EPIC and both results were compared. For the simulation of erosion the described information of the soil profile were used, and the soil albedo was calculated using the Bauner formula (10).

A= 0.6 / EXP (0.4 x MO)

Where: A= soil albedo

MO= Organic matter of the soil (%)

Finally, it was proceeded to simulate yield in dry matter with EPIC, in the three forage species for the next 100 years.

Results and discussion

Soil classification

The profile presented a superficial cover of 8 cm, correspondent to an AP horizon with evidences of faunistic activity. In this phase, concentrates the highest quantity of roots, and the highest content of organic matter and it has a well developed structure of sub-angular blocks. After the 31 cm, it was observed part of horizon C, and after 41 cm is presented a hard horizon (hardened) genetically named as Crt. In general, all the profile presented an apparent high density showing the hardened of this soil. The coloration of dark colors on the superficial area turned into dun grayish at the end, on the deepest part obtained a yellowish coloration (table 1). These characteristics, among to the laboratory analysis (table 2) allowed to classify the soil as Lithic Ustorthents.

Use of solar radiation

Results are shown in figure 1

Table 1. Description of the soil profile

Depth	Horizon	Characteristics of the horizon
0 - 8	Ap	Dun color (10 YR 5/3) being dry and dark dun (10 YR 3/3) being wet. With loamy texture, well developed sub-angular block structures, had consisted being dry, plastic and sticky being wet, slow permeability, thin and abundant roots and few means, few fine pores and scarce media. Excrement deposit in the pores, few fissures of 3-5 m thickness, presence of ants. No reaction to HCl and slightly to H2O2 in cold, horizontal transition and marked by color.
8 - 31/36	A	Gray color (10 YR 5/1) being dry and very dark grayish gray (10 YR 3/2) being dry, clayey loamy texture, well developed sub-angular block structure, slightly hard consistence being dry and sticky being wet, slow permeability, abundant thin roots, medium and few thick. Few and discontinuous fine pores, few fissures < 3 mm. Without reaction to HCl and little reaction to H2O2 being cold. Curve transition and marked by the color.
31/36 – 41/45	AC	Gray color (10 YR 6/1) being dry and very dark grayish gray (10 YR 3/2) being wet, clayey loamy texture, well developed sub-angular block structure, slightly hard consistency being dry, and sticky being wet, slow permeability. Abundant thin roots, medium and few thick, few and discontinuous pores, few fissures < 3 mm, without reaction to HCl and a little reaction to H2O2 being cold. Curve transition and market by color.
41/45 – 58	Crt	Gray color (10 YR 6/1) being dry and very dark grayish gray (10 YR 3/2) being wet, clayey texture, well developed sub-angular block structure, very hard consistency being dry, and plastic and sticky being wet, moderate permeability. Scarce fine roots, few discontinuous fine pores, clayey coating. No reaction to HCl and a little to H2O2 being cold. Curve transition and market by color.

Table 1. Description of the soil profile (Continue)

Depth	Horizon	Characteristics of the horizon
58 - 71/73	Crt2	Light dun gray color (10 YR 6/2) being dry, and yellowish dun (10 YR 5/4) being wet, clayey texture, well developed sub-angular blocks structure, hard consistency being dry, and plastic consistency being wet, moderate permeability. Scarce fine roots, few discontinuous fine pores, clayey coatings and aggregated Mn deposits. No reaction to HCl and a little to H202 in cold. Curve and slender transition.
71/73 - 89/90	Crt3	Light dun gray color (10 YR 6/2) being dry and yellowish dun (10 YR 5/4) being wet, clayey texture, well develop sub-angular block structured, hard consistency being dry, and plastic being cold, moderate permeability. Scarce fine roots, few fine discontinuous pores, clayey coatings and aggregated Mn deposits. No reaction to HCl and a little to H2O2 being cold. Curve and slender transition.
89/90 – 105	C	Very pale dun color (10 YR 7/4) being dry, and dark yellowish dun (10 YR 3/6) being wet, clayey lime texture, moderate development of sub-angular blocks structures, very hard consistency being dry, plastic and sticky being wet, moderate permeability. Rare and dead fine roots, scarce fine pores and presence of Mn of the aggregated faces. No reaction to HCl and little reaction to H2O2 being wet.

and indicate that Rhodes fodder was more efficient in the use of radiation when producing 1.77 g MS MJ^{-1} of intercepted radiation. In this case Alfalfa presented the lowest efficiency in the use of radiation with a value of 1.17. In general terms, the efficiency in the use of radiation of Rhodes fodder was 28.25 and 33.68% superior to the one of native fodder and alfalfa respectively. These results agree with those reported by Sinclair and Muchow (13), who indicated that grasses are more efficient in the use of radiation to create biomass, due to legumes use a big quantity of the intercepted radiation to create other compounds as proteins. Rhodes fodder was the one that presented a higher efficiency in the use of the photosynthetically active radiation, mainly due to the high conversion of energy into biomass, and to the highest exposed foliar area. In this matter,

Table 2. Laboratory determinations to classify the soil profile

		Color			Soluble cathions			
Prof cm	pH	Dry	Wet	CE dS m^{-1}	Na meq l^{-1}	K meq l^{-1}	Ca meq l^{-1}	Mg meq l^{-1}
0-8	6.6	10YR 5/3	10YR 3/3	0.34	0.27	0.22	9.60	1.00
8-31	7.2	10 YR 5/1	10YR 3/2	0.28	0.74	0.16	4.00	5.20
31-41	7.3	10YR 6/2	10YR 4/4	0.28	0.97	0.11	5.00	1.40
41-58	7.4	10YR 6/1	10YR 3/2	0.26	0.81	0.11	3.40	2.40
58-71	7.0	10YR 6/2	10YR 5/4	0.32	1.08	0.12	3.50	1.50
71-89	7.0	10YR 6/2	10YR 5/4	0.60	1.53	0.16	8.00	1.00
89-105	6.8	10YR 7/4	10YR 3/6	0.61	1.48	0.17	7.50	1.70

					Changeable cathions			
Prof cm	CIC cmol kg^{-1}	CO3 %	MO %	CO %	Na cmol kg^{-1}	K cmol kg^{-1}	Ca cmol kg^{-1}	Mg cmol kg^{-1}
0-8	24.38	0.49	1.25	0.73	0.10	0.42	10.72	6.08
8-31	34.34	0.61	1.75	1.02	0.37	0.86	18.72	4.64
31-41	36.25	0.88	2.13	1.24	0.68	0.66	20.80	1.60
41-58	36.04	0.58	1.50	0.87	0.86	0.99	24.00	2.40
58-71	32.44	0.36	1.38	0.80	0.72	0.78	18.88	4.32
71-89	37.31	0.45	1.50	0.87	0.68	0.78	18.72	3.04
89-105	43.46	0.76	1.75	1.02	0.90	1.10	22.40	1.92

			Mechanical analysis					
Prof cm	PSB %	Da Mg m^{-3}	Sand %	Clay %	limo %	Texture type	P ppm	Humidity %
0-8	58.36	1.62	37.80	15.59	46.61	franco	< 250	5.77
8-31	71.59	1.64	14.30	38.79	46.91	fr. arc. Limoso	< 250	23.17
31-41	65.50	1.70	31.30	29.99	38.71	fr. Arcilloso	< 250	21.51
41-58	78.39	1.70	7.70	49.99	42.31	arc. Limoso	< 250	29.34
58-71	76.18	1.70	15.70	48.39	35.91	arcilloso	< 250	28.00
71-89	62.24	1.65	20.60	34.79	44.61	fr. Arcilloso	< 250	24.19
89-105	60.57	1.59	13.40	31.59	55.01	fr. Arc. limoso	< 250	24.19

Prof = Depth
CE= Electrical conductivity
CIC= cationic interchange capacity
CO$_3$ = Total carbonates
MO = Organic matter
CO = Organic carbon
Da = Apparent density
P= Soluble phosphorus in citric acid
PSB = Saturation percentage of base

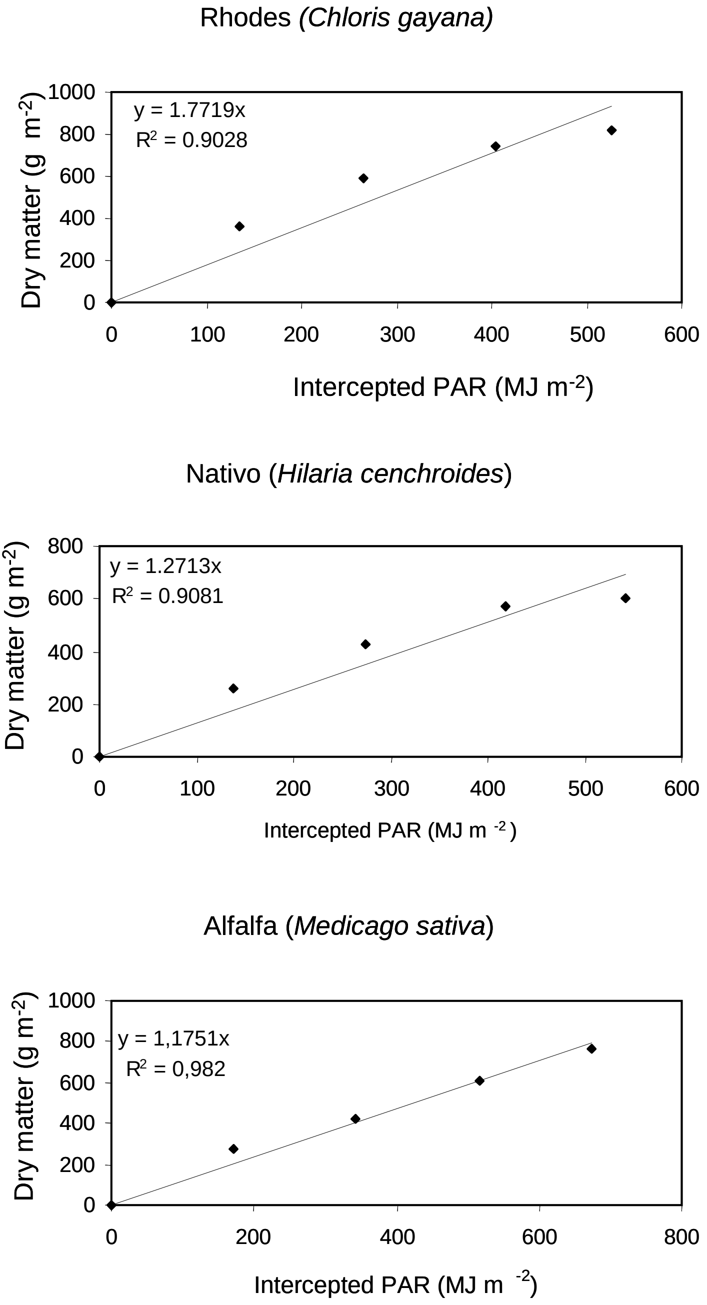


Figure 1. Efficient use of the sun radiation in accumulation of dry matter

Uresti (16) mentions that the interception of radiation of crops depends on their green foliar area, and Andrades *et al.* (1) indicate that *Panicun maximun* presented higher efficiency in the use of solar radiation than *rachiaria brizantha* and *Brachiaria decumbens* as a result of the increment of their foliar area. Likewise, Kiniry *et al.* (7), say that the interception of the sun radiation depends on the foliar area, therefore IPAR values in the crops decrease with the age.

When comparing the values of the efficient use of sun radiation (RUE) observed with the simulated values, is found that for these fodders the simulated values were superior to those observed, which indicates that EPIC model overestimated RUE values. The highest approximation of the simulated values with those observed corresponded to the native fodder (figure 2), therefore, it can be affirm that in normal conditions of the basin, the EPIC program is more effective in the simulation of the efficient use of the radiation by this native fodder compared to the Rhodes fodder and with alfalfa. On this matter, Santamaría *et al.* (11), indicate that yields in dry matter of alfalfa are significantly related with those estimated with the EPIC model, with a $r^2 = 0.92$ and $P<0.05$, in different ecological environment of Mexico.

Erosion and simulated yield

Using the universal equation of soil loss the loss values of the soil were calculated on the Rhodes, native and alfalfa lawn, and loss were simulated using the EPIC model. The highest calculated and simulated loss corresponded to the alfalfa lawn, and the lowest to the Rhodes fodder (figure 3). When comparing the simulated values with EPIC to the calculated values, it was observed an overestimation of the erosion of the model, it means, the simulated values

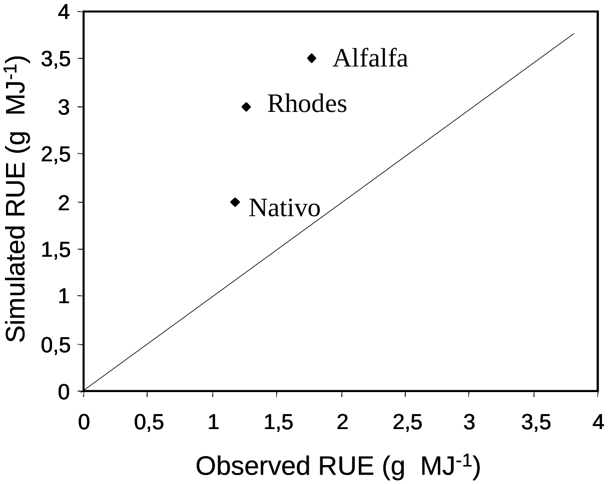


Figure 2. Observed and simulated RUE relation in forage species

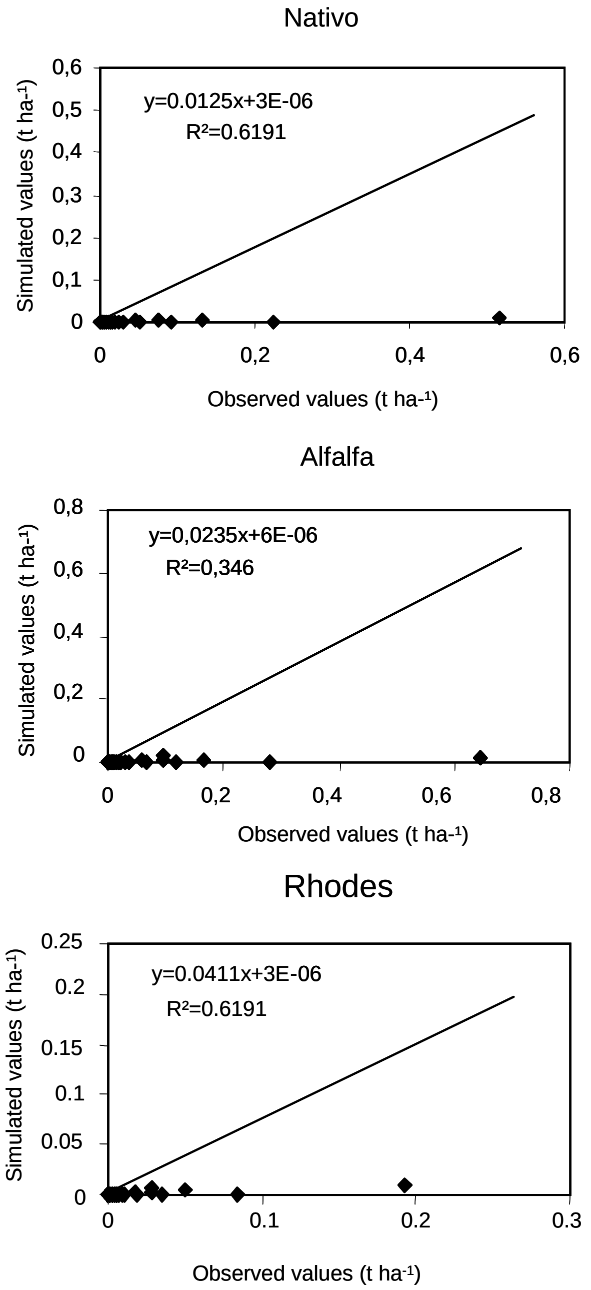
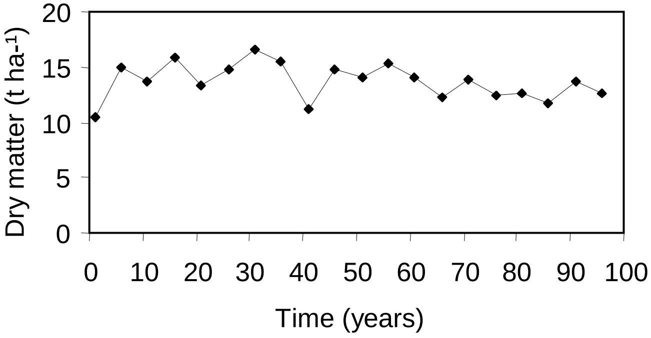


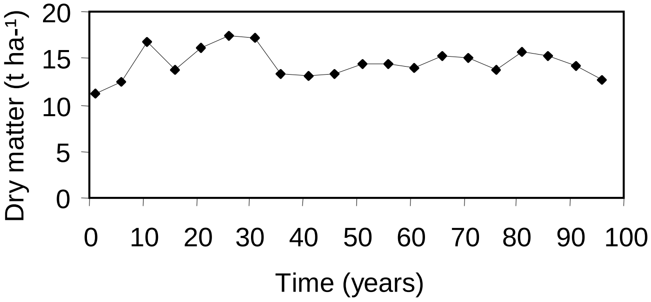
Figure 3. Observed and simulated water erosion

with EPIC were under the calculated values. These results agree with those reported by Muñoz (10), who working with conventional and conservation farming observed that values of water erosion for both farming systems were very under the acceptable limits of soil loss. Likewise, Arroyabe *et al.* (2), indicate that there are discrepancies between the observed and simulated values of soil loss in smallholdings with stubble cover made of ryegrass. The EPIC software made an overestimation of the erosion when comparing it to the obtained values using the Universal Equation of Soil Loss; however, it has been proved that EUPS tends to do overestimations of the erosion in most cases (16).

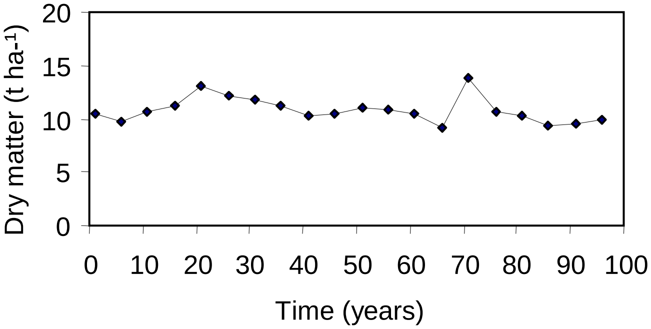
The simulated productive potential of the three species using EPIC is shown on figure 4, where can be observed that the highest variation corresponded to the alfalfa lawn, while yields for grass had a lower variation mainly due to the forage grass keep a higher cover on the soil, therefore, soil loss by erosion is very little. On the simulation done, was observed a yield increment in dry matter of 0.8 t ha^{-1} and 3.7 t ha^{-1} when comparing Rhodes fodder with alfalfa and native fodder respectively. The maximum yield of alfalfa was presented on the simulated years 31 and 36, observing values of 16.58 and 15.54 t ha^{-1} of dry matter, while Rhodes grass showed this condition in years 26 and 31, with values of 17.44 and 17.27 t ha^{-1}. Native grass showed the highest simulated yields in the year 21 and 71, being 13.15 and 13.74 t ha^{-1}, respectively. In the case of Alfalfa, the simulated yields were those that had a highest variation every five years, presenting as minimum value 10.5 t ha^{-1} in the first year, and the maximum of 16.58 t ha^{-1} in year 31. On the other hand, Rhodes grass had a more uniform behavior throughout the simulation being the minimum value of 11.11 t ha^{-1} the first year, and the maximum of 17.44 ha^{-1} in the year 26. The highest uniformity of yields was observed after year 36. To the native grass, the simulated yields were more stable throughout the simulation process, excepting in years 21 and 71, where were the highest yields. The minimum value of yield was of 9.17 t ha^{-1} in the year 66. The simulated yields for the three species were similar to the obtained information in the field, so it can be said that the EPIC software produces acceptable results on the production simulation of dry matter in this lawns on the local conditions. These results correspond to well-handled lawns, where the soil cover is around of 100%, therefore the erosion is very low, and does not affect the simulated yields throughout the time.



Alfalfa (Medicago sativa)



Rhodes (Chloris gayana)



Nativo (Hilaria cenchroides)

Figure 4. Simulated values of yields in dry matter

Conclusions

On the conditions of the basin the most effective model is EPIC in the use simulation of solar radiation by the native grass compared to the introduced forage species (Rhodes grass and alfalfa).

When EPIC is used to simulate the water erosion in these lawns, the model tend to overestimate the results. In well-handled lawns, where the erosion problems are minimum, the model does satisfactorily the yield simulation in dry matter of the forage species.

Literature cited

1.Andrades H, I. Mahammad, F. Jiménez, B. Finejan and D. Kass. 2000. Dinámica productiva de sistemas silvopastoriles con *Acacia mangium* y *Eucalyptus deglupta* en el trópico húmedo. Agroforesteria de las Américas 7 (26).

2. Arroyave J.F, J.A. Tapasco, B. Rivera and F. Obando. 2000. Viabilidad del uso del modelo EPIC para estimar pérdidas de suelo en zonas de laderas. Universidad de Caldas, Manizales, Colombia. 8 p.

3. Betancourt, Y. P, J. L. Oropeza, B. Figueroa, V. Ordaz, C. Ortiz and A. Hernández .2000. Pérdidas de suelo y potencial hidrológico en parcelas con coberturas vegetativas de especies forrajeras. TERRA. 8 (3): 263-275.

4. Cuanalo, H. 1990. Manual para la descripción de perfiles de suelo en el campo. 3ra edición. Colegio de Postgraduados. Chapingo, México. 40 p.

5. Cruz, P. 1995. Use of RUE concept for analyzing growth of pure and mixed tropical forage crops. In: Ecophysiology of Tropical Intercropping. INRA Edition. Paris. p 319-330.

6. Figueroa, S. B, A. Orozco, T. H. Cortez and L. J. Pimentel. 1991. Manual de predicción de pérdidas de suelo por erosión. CP-SARH. México. 150 p.

7. Kiniry, J.R, C.A. Jones, J.C. O´Toole, R. Blanchet, M. Cabelguenne and D.A. Spanel. 1989. Radiation-Use Efficiency in accumulation prior to grain-filling for five grain-crop species. Field Crops Research. 20: 51-64.

8. López, M.R. 1996. Estimación de índices de erosividad a partir de la lámina diaria de lluvia. Universidad Autónoma Chapingo. Chapingo, México. 98 p.

9. Mitchell G., R. Griggs, V. Benson and J. Williams. 1993. The EPIC model environmental policy integrated climate formally Erosion Productivity Impact Calculator. The Texas Agriculture Experimental Station. USDA. 234 p.

10. Muñoz, A. R. 1997. Empleo del modelo EPIC para determinar el efecto de la labranza de conservación sobre el cultivo de trigo. Colegio de Postgraduados en Ciencias Agrícolas. Montecillo, México. 112 p.

11. Santamaría C. J, H .G Núñez, G. G. Medina, C.J. Ruiz, L .M. Tiscareño and G. M. Quiroga. 2000. Evaluación del modelo EPIC para estimar el potencial productivo de alfalfa (*Medicago sativa* L.) en diferentes ambientes ecológicos de México. Tec. Pec. Mex. 38 (2): 151-161.

12. Soil Survey Staff. 1998. Key to soil taxonomy . 8th edition. United States Department of Agriculture. Natural Resources Conservation Service. 306 p.

13. Sinclair , R.T and R.C. Muchow. 1999. Radiation Use Efficiency. Advances in Agronomic 65. Academic Press. Pp 215-265.

14. Silva, E. O. 1995. Descripción general de algunos modelos de simulación de erosión. Venesuelos 3 (1): 30-37.

15. Van Reecwijk, L. P. 1995. Procedures for soil analysis. Tech. Pap. Nº 9. 5th ed. ISRIC. Wageningen, Netherlands. 51 p.

16. Uresti, G. J. 2000. Modelos para simular la producción potencial del maíz y del frijol, y la tasa de erosión del suelo en la zona tropical de México. Colegio de Postgraduados. Montecillo, México. 251 p.

17. Uresti, G. J., B. Figueroa, V. González, C. Ortiz, A. Turrent. 2001. Modelos para simular el crecimiento y producción potencial del maíz y la tasa diaria de erosión en zonas tropicales. 14ª Reunión Científica, Tecnológica-Forestal y Agropecuaria, Veracruz, México.